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Evaluation of Drainage System in Simorejo Settlement Area, Simomulyo Village, Sukomanunggal Sub-District, Surabaya City

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Abstract

Flooding frequently occurs in the Simorejo Settlement Area, Simomulyo Village, Sukomanunggal Sub-District, Surabaya City, Indonesia. Recent flooding revealed that the existing channel's capacity was insufficient to handle flood discharge. Therefore, an evaluation of the drainage channels was carried out to determine design and existing flood discharges and channel re-designing measures. Rain data from 2012 to 2021, for the last decade, was used in the evaluation. Maximum rainfall was calculated using the arithmetic method, while design and existing channel discharges were calculated based on the rational method with a maximum rainfall of 2 years, 5 years, and 10 years. The calculation results showed that the channel condition was unable to accommodate the planned flood discharge with a 2-year, 5-year, and 10-year return period. Consequently, re-designing was carried out using a trial and error method until the channel was able to accommodate the design of flood discharge. The re-designing process resulted in an enlarged drainage channel cross-section with dimensions of 1.2 m x 1 m x 1 m.

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1. Introduction

Drainage is a system designed to remove excess water and waste originating from residential, industrial, and commercial areas, roads, and other pavements (Arifin 2018). The increasing residential development in major cities such as Surabaya is often not accompanied by a proper spatial management system, particularly in drainage management. This results in a decrease in the infiltration rate of rainwater entering the soil and a greater surface flow. Consequently, water overflows more than the capacity of the drainage channel, resulting in floods. The issue of flooding in the Simorejo area, Simomulyo Village, Sukomanunggal Sub-District, Surabaya City has not been fully resolved. Floods often occur and become a regular occurrence when it rains, resulting in an elevation of the surface between one house and another. This is due to the fact that the canal can no longer accommodate runoff water, resulting in an impact on the amount of water runoff that goes to the drainage channel, which eventually flows down the street, causing flooding. Therefore, it is necessary to analyse the capacity of the drainage channel to determine whether the channel can accommodate rainwater runoff discharge adequately.

2. Materials and Methods

2.1 Theoretical Frame Work

The purpose of this study is to analyse the amount of flood discharge flowing in the channel, assess the channel's capacity, and redesign the cross-section of the drainage channel. The research uses arithmetic methods, rational methods, and trial and error methods.

2.2 Research Location

The research is conducted in the Simorejo Residential area, situated along Jl. Simorejo, Simomulyo Village, Sukomanunggal District, Surabaya City, as shown in Figure 1 with a yellow line polygon. The research study boundary is to the north of Jl. Simorejo Gg. II, west of Jl. Simorejo Gg. III, south of Jl. Simorejo Gg. XXXVII and Jl. Kali Kundang, and east of Jl. East Simorejo Gg. III.

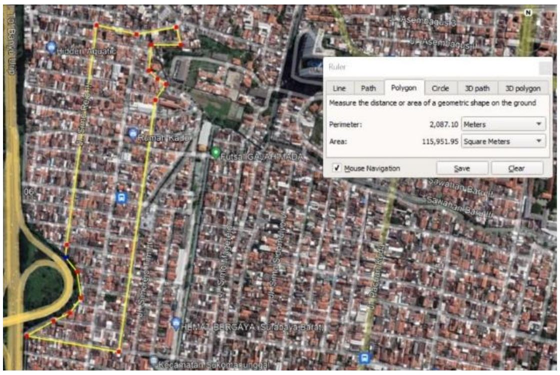

Figure 2. Research Location

2.3 Data

This stage involves data collection, which is necessary to obtain the required research material. It includes field observations to directly observe activities and obtain data for writing purposes. The data for this study consisted of primary and secondary data. Primary data includes field surveys of drainage channel dimensions and documentation, while secondary data consist of rainfall data for a 10-year return period from 2012-2021, channel cross-sectional dimensions, and a study area map.

2.4 Analysis Method

2.4.1 Hydrological Analysis

Hydrological analysis is conducted to determine the hydrological parameters in detail and to produce a planned flood discharge. The analysis involves the examination of daily rainfall data from 5 rain stations over a period of 10 years. Once the annual average rainfall from the stations is obtained, regional rainfall calculations are performed using the arithmetic method. Subsequently, an analysis of the frequency distribution is carried out using the Gumbel distribution method, the normal distribution, and the Pearson III log distribution for 3 return periods - 2 years, 5 years, and 10 years. The results from the three distributions are subjected to a fit test using the Chi-Square test and the Smirnov-Kolmogorov test to determine if the hypothesis can be accepted. After the distribution compatibility test is carried out, rain concentration analysis calculation is performed for each channel. Once the rain concentration values are obtained, the rain intensity is calculated using the Mononobe method. Finally, the design flood discharge is determined for each channel using the rational method for a return period of 2 years, 5 years, and 10 years.

2.4.2 Hydraulics Analysis

Hydraulic analysis is carried out to determine how much the cross-sectional ability of the channel can accommodate the discharge that enters the drainage channel. The analysis is conducted by collecting existing channel data in the form of channel depth (h), channel wall slope (z), channel Manning coefficient (n), length of each channel (L), and channel width (b). These data are used to calculate the wet cross-sectional area (A), wet perimeter (P), hydraulic radius (R), flow velocity (V), and then obtain the discharge of the existing channel for each channel.

2.4.3 Drainage Channel Evaluation

Evaluation is conducted by comparing the planned flood discharge with the existing channel discharge. If the existing channel is found to be inadequate, a solution is proposed by redesigning the channel. When redesigning the drainage, predetermined standards are used for both the discharge plan and the analysis method, the height of the guard, the channel structure, etc. (Kusuma, 2017). In designing the dimensions of the channel, efforts must be made to obtain an economical cross-sectional dimension. Channels that are too large are not economical, while channels that are too small have a high loss rate (Milliandi, 2022).

3. Result and Discussion

3.1 Hydrological Analysis

The analysis is carried out with rainfall data of the the last 10 years from 5 rain stations which are Simo, Gubeng, Gunung Sari, Wonokromo and Kedung Cowek from 2012 until 2021. Hydrological analysis is consisted of rainfall data analysis, distribution compatibility test, rainfall data concentration analysis, rainfall intensity analysis, and flood discharge design analysis.

3.1.1. Rainfall Data Analysis

This analysis is carried out with rainfall data in order to find the average value of rainfall each year from 5 rain stations with a 10 years period. There are 3 used methods in this analysis, which are Gumbel distribution, normal distribution, and log Pearson type III distribution. The rainfall data analysis is presented in these tables below.

Table 1. The Average Value of Rainfall Data from 10 Years Period.

No.	Observation Year	Mean
1	2012	79,2
2	2013	86,2
3	2014	84,2
4	2015	67,2
5	2016	97,8
6	2017	109,6
7	2018	68,6
8	2019	72,2
9	2020	99,8
10	2021	95
n = 10		859

Table 2. The Result of Gumbel Distribution

Return Period (years)	Xr	Kt	Sd	Xt (mm)
2	85,98	-0,1355	14,4197	84,0259
5	85,98	1,0581	14,4197	101,2370
10	85,98	1,8483	14,4197	112,6322

Table 3. The Result of Normal Distribution

Return Period (years)	Xr	Kt	Sd	Xt (mm)
2	85,98	0	14,4197	85,9800
5	85,98	0,84	14,4197	98,0925
10	85,98	1,28	14,4197	104,4372

Table 4. The Result of Log Pearson Type III Distribution

Return Period (years)	Log Xr	Kt	Sd Log X	Log Xt	Xt (mm)
2	1,92	0	0,073	1,928	84,800
5	1,92	0,84	0,073	1,990	97,800
10	1,92	1,28	0,073	2,023	105,400

3.1.2. Goodness of Fit Test

Table 5. Recapitulation of Fit Test

Distribution Method	Fit Test			
	Chi-Square Test			
	Xh^2	Mark	X^2cr	Description
Gumbel	1	<	5,991	OK
Normal	1	<	5,991	OK
Log Pearson Type III	3	<	5,991	OK
Distribution Method	**Fit Test**			
	Smirnov-Kolmogorov Test			
	D_{max}	**Mark**	D_o	**Description**
Gumbel	0,0519	<	0,41	OK
Normal	0,1042	<	0,41	OK
Log Pearson Type III	0,1042	<	0,41	OK

This test is conducted to find the most suitable method. From Table 5 above, it can be concluded that all distribution methods are acceptable. Therefore, the Gumbel distribution method, which has the smallest Xh^2 and D_{max} values, is chosen for the recalculation of rainfall.

3.1.3. Rainfall Concentration Time Analysis

Rainfall concentration time (tc) is calculated on each channel. The analysis is carried out for every channel, because each channel has different cross section. The result of analysis is presented in Table 6. The example of this analysis is taken for channel of Tertiary 1.

$$tc = \left(\frac{0,87 \, . \, L^2}{1000 \, . \, S}\right)^{0,385}$$

$$= \left(\frac{0,87 \, . \, 6471^2}{1000 \, . \, 0,000137}\right)^{0,385}$$

= 13,750 hours

Table 6. Rainfall Concentration Time Results

Channel Name	Length (m)	S	tc (hour)
Tertiary 1	6471	0,000137	13,75
Tertiary 2	1255	0,000708	2,477
Tertiary 3	800	0,001111	0,894
Tertiary 4	2144	0,000415	4,033
Scondary 2	781	0,001138	0,626
Scondary 1	470	0,004726	0,399
Primary Sawahan	502	0,006644	0,523
Primary Asemrowo	885	0,003765	1,451
Primary Krembangan	1,239	0,00269	3,517

3.1.4. Rainfall Intensity Analysis

Rainfall intensity is analysed by using the mononobe method. Analysis is carried out in 3 returns period which are 2 years, 5 years, and 10 years. Rainfall data used is from the calculation of Gumbel distribution method. The result of rain intensity for each channel is shown in this Table 7. The rain intensity for 2 years of period is made under this calculation.

$$I_2 = \frac{R24}{24} \, . \left(\frac{24}{tc}\right)^{\frac{2}{3}}$$

$$= \frac{84,026}{24} \, . \left(\frac{24}{13,750}\right)^{\frac{2}{3}}$$

= 5,075 mm/hour

Table 7. The Result of Rainfall Intensity

Channel Name	tc (hour)	Rainfall Intensity (mm/hour)		
		2 years	5 years	10 years
		84	101,2	112,6
Tertiary 1	13,75	5,07	6,115	6,803
Tertiary 2	2,477	15,9	19,17	21,32
Tertiary 3	0,894	31,3	37,83	42,08
Tertiary 4	4,033	11,4	13,85	15,41
Scondary 2	0,626	39,7	47,94	53,33
Scondary 1	0,399	53,7	64,73	72,01
Primary Sawahan	0,523	44,8	54,05	60,13
Primary Asemrowo	1,451	22,7	27,38	30,47
Primary Krembangan	3,517	12,5	15,17	16,88

3.1.5. Flood Discharge Design Analysis

The calculation of flood design discharge uses rational method. Like Rainfall intensity analysis, this analysis is carried out in 2 years, 5 years, and 10 years of return period. The result of calculation is presented in Table 8. The example for this analysis is taken from calculation of 2 years of return period.

$Q_2 = 0{,}00278 \times C \times It \times A$

$= 0{,}00278 \times 0{,}802 \times 5{,}075 \times 11{,}954$

$= 0{,}135\ m^3/s$

Table 8. The Recapitulation of Flood Discharge Design

Channel Name	Q (m³/sec)		
	2 years	5 years	10 years
Tertiary 1	0,135	0,163	0,181
Tertiary 2	0,098	0,118	0,132
Tertiary 3	0,065	0,078	0,087
Tertiary 4	0,102	0,123	0,137
Scondary 2	0,059	0,072	0,080
Scondary 1	0,080	0,096	0,107
Primary Sawahan	0,114	0,137	0,152
Primary Asemrowo	0,167	0,202	0,224
Primary Krembangan	0,242	0,292	0,324

3.2 Hydraulics Analysis

In this study, hydraulic analysis aims to determine the capability of cross-sectional capacity for the channel to accommodate discharge design. 2 years, 5 years, and 10 years of return period discharge is shown in Table 9, Table 10, and Table 11.

Table 9. 2 Years of Return Period Discharge

Channel Name	Channel Type	Q (m³/sec)
Tertiary 1	Trapezoid	0,084
Tertiary 2	Trapezoid	0,191
Tertiary 3	Trapezoid	0,239
Tertiary 4	Trapezoid	0,146
Scondary 2	Trapezoid	0,242
Scondary 1	Trapezoid	116,319
Primary Sawahan	Trapezoid	399,576
Primary Asemrowo	Trapezoid	688,828
Primary Krembangan	Trapezoid	702,588

Table 10. 5 Years of Return Period Discharge

Channel Name	Channel Type	Q (m³/sec)
Tertiary 1	Trapezoid	0,084
Tertiary 2	Trapezoid	0,191
Tertiary 3	Trapezoid	0,239
Tertiary 4	Trapezoid	0,146
Scondary 2	Trapezoid	0,242
Scondary 1	Trapezoid	116,319
Primary Sawahan	Trapezoid	399,576
Primary Asemrowo	Trapezoid	688,828
Primary Krembangan	Trapezoid	702,588

Table 11. 10 Years of Return Period Discharge

Channel Name	Channel Type	Q (m³/sec)
Tertiary 1	Trapezoid	0,084
Tertiary 2	Trapezoid	0,191
Tertiary 3	Trapezoid	0,239
Tertiary 4	Trapezoid	0,146
Scondary 2	Trapezoid	0,242
Scondary 1	Trapezoid	116,319
Primary Sawahan	Trapezoid	399,576
Primary Asemrowo	Trapezoid	688,828
Primary Krembangan	Trapezoid	702,588

3.3 Drainage Channel Evaluation

Channel evaluation is carried out by comparing flood discharge design of each drainage channel with existing channel discharge as shown in Table 12, Table 13, and Table 14. The channel discharge will be compared with 2 years, 5 years, and 10 years of return period.

Table 12. Drainage Channel Evaluation for 2 years of return period discharge

Channel Name	Return Period 2 Year (Q_2)		
	Q Exst (m³/sec)	Q Plan (m³/sec)	Condition
Tertiary 1	0,084	0,135	Not OK
Tertiary 2	0,191	0,098	OK
Tertiary 3	0,239	0,065	OK
Tertiary 4	0,146	0,102	OK
Scondary 2	0,242	0,059	OK
Scondary 1	116,319	0,080	OK
Primary Sawahan	399,576	0,114	OK
Primary Asemrowo	688,828	0,167	OK
Primary Krembangan	702,588	0,242	OK

Table 13. Drainage Channel Evaluation for 5 years of return period discharge

Channel Name	Return Period 5 Year (Q_5)		
	Q Exst (m³/sec)	Q Plan (m³/sec)	Condition
Tertiary 1	0,084	0,163	Not OK
Tertiary 2	0,191	0,118	OK
Tertiary 3	0,239	0,078	OK
Tertiary 4	0,146	0,123	OK
Scondary 2	0,242	0,072	OK
Scondary 1	116,319	0,096	OK
Primary Sawahan	399,576	0,137	OK
Primary Asemrowo	688,828	0,202	OK
Primary Krembangan	702,588	0,292	OK

Table 14. Drainage Channel Evaluation for 10 years of return period discharge

Channel Name	Return Period 10 Year (Q_{10})		
	Q Exst (m³/sec)	Q Plan (m³/sec)	Condition
Tertiary 1	0,084	0,181	Not OK
Tertiary 2	0,191	0,132	OK
Tertiary 3	0,239	0,087	OK
Tertiary 4	0,146	0,137	OK
Scondary 2	0,242	0,080	OK
Scondary 1	116,319	0,107	OK
Primary Sawahan	399,576	0,152	OK
Primary Asemrowo	688,828	0,224	OK
Primary Krembangan	702,588	0,181	OK

Tertiary 1 channel is unable to accommodate flood discharge design. Therefore in evaluating the existing channel, one of the steps that can be taken is enlarging the cross section and depth of the channel. So that, the capacity of the channel is capable to accommodate the flood discharge design. The results of re-design channel with 10 years of return period is obtained with trial and error. The results of the channel is presented in Table 13.

Table 15. Result of Re-Design Channel with 10 Years Return Period

Channel Name	Q Exist (m^3/sec)	Q Plan (m^3/sec)	Condition
Tertiary 1	0,445	0,181	OK
Tertiary 2	1,011	0,132	OK
Tertiary 3	1,266	0,087	OK
Tertiary 4	0,774	0,137	OK
Scondary 2	1,282	0,080	OK
Scondary 1	116,319	0,107	OK
Primary Sawahan	399,576	0,152	OK
Primary Asemrowo	688,828	0,224	OK
Primary Krembangan	702,588	0,324	OK

Based on the results above, the re-design based on 10 years return period produces new cross-sections, which is able to accommodate rain discharge.

- The channel of Tertiary 1 with a dimension of 1,2 × 1 × 1 m, which is able to accommodate 0,310 m^3/s of rain discharge
- The channel of Tertiary 2 with a dimension of 1,2 × 1 × 1 m, which is able to accommodate 0,703 m^3/s of rain discharge
- The channel of Tertiary 3 with a dimension of 1,2 × 1 × 1 m, which is able to accommodate 0,881 m^3/s of rain discharge
- The channel of Tertiary 4 with a dimension of 1,2 × 1 × 1 m, which is able to accommodate 0,538 m^3/s of rain discharge
- The channel of Secondary 2 with a dimension of 1,2 × 1 × 1 m, which is able to accommodate 2,084 m^3/s of rain discharge

4. Conclusion

The high inundation case frequently occurs in the Simorejo residential area during the rainy season, becoming a regular problem due to the drainage canals' inadequate capacity to accommodate and drain the excess water. Therefore, this research aims to propose alternative solutions to address the inundation problem. The drainage channel capacity in the Simorejo residential area is as follows: tertiary 1 = 0,084 m^3/s, tertiary 2 = 0,191 m^3/s, tertiary 3 = 0,239 m^3/s, tertiary 4 = 0,146 m^3/s, and secondary channel 2 = 0,242 m^3/s.

After calculating the design discharge, the average design discharge for the Simorejo residential area channels, considering a 2-year return period for tertiary 1-4 and secondary 2, is estimated to be 0,092 m^3/s. The average planned discharge for a 5-year return period for tertiary 1-4 and secondary 2 channels is projected to be 0,111 m^3/s. Additionally, the average planned discharge for a 10-year return period for tertiary 1-4 and secondary 2 channels is anticipated to be 0,123 m^3/s.

Upon conducting research and analysis on the channels in the Simorejo residential area, it is discovered that the existing trapezoidal-shaped canals are incapable of accommodating rainfall and preventing flooding. Thus, it is necessary to redesign the channel's cross-section and depth to create dimensions that can effectively manage flood discharge in tertiary channels 1-4 and secondary channel 2. The proposed dimensions for the redesigned channel are 1,2 m of width, 1 m of depth, and 1 m of height.

5. Acknowledgment

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6. Author's Note

All of the content written in this article is original as it summarizes my studies with Faradlillah Saves. The contents of this article were reviewed during my thesis defense at the Department of Civil Engineering, University of 17 Agustus 1945 Surabaya.

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